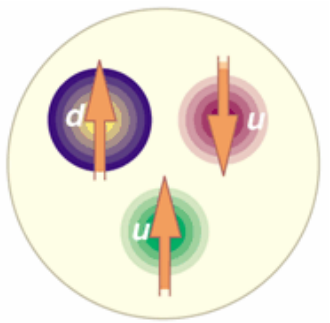
Summary from Physics Working Group Discussions

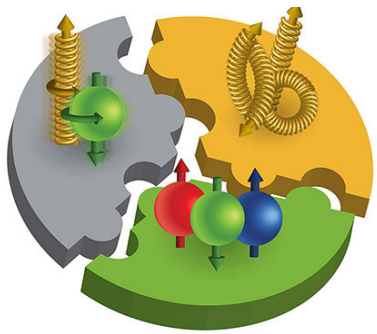
Bo-Wen Xiao

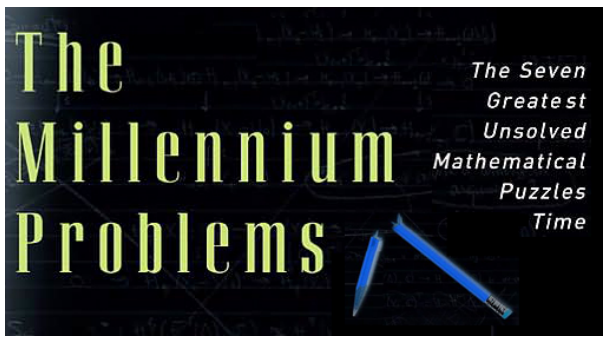
Institute of Particle Physics, Central China Normal University

Challenges Pertaining to Hadron Structure

- How does the spin of proton arise? (Spin puzzle)
- How does the mass of the proton arise? (Mass gap)
- What are the emergent properties of dense system of gluons?
- Need to map the quark and gluon inside the proton in 3D.
- Proton radius puzzle.



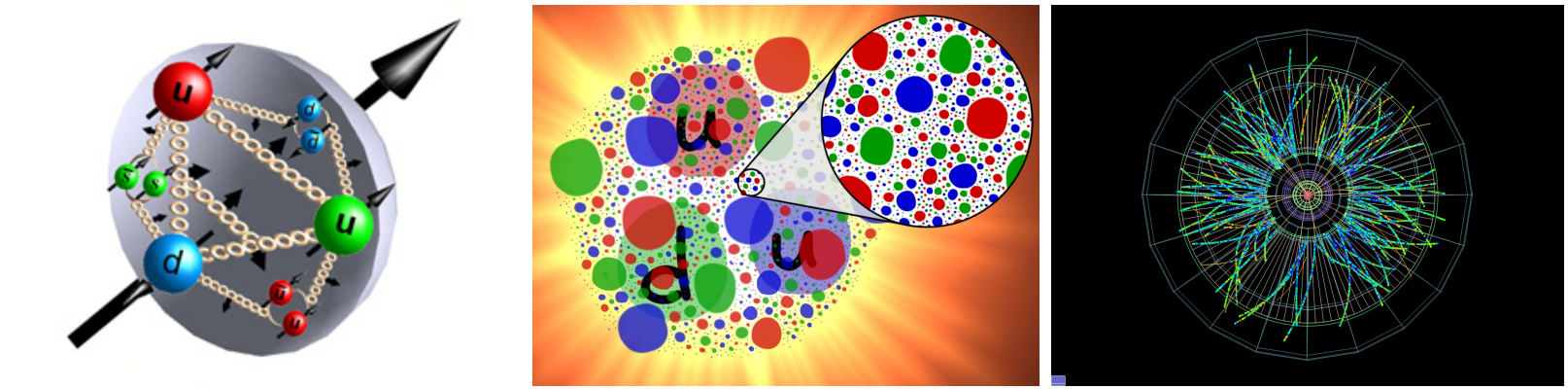




[Evaluation of EIC by NAS]

Ultimate goals in the study of proton structure

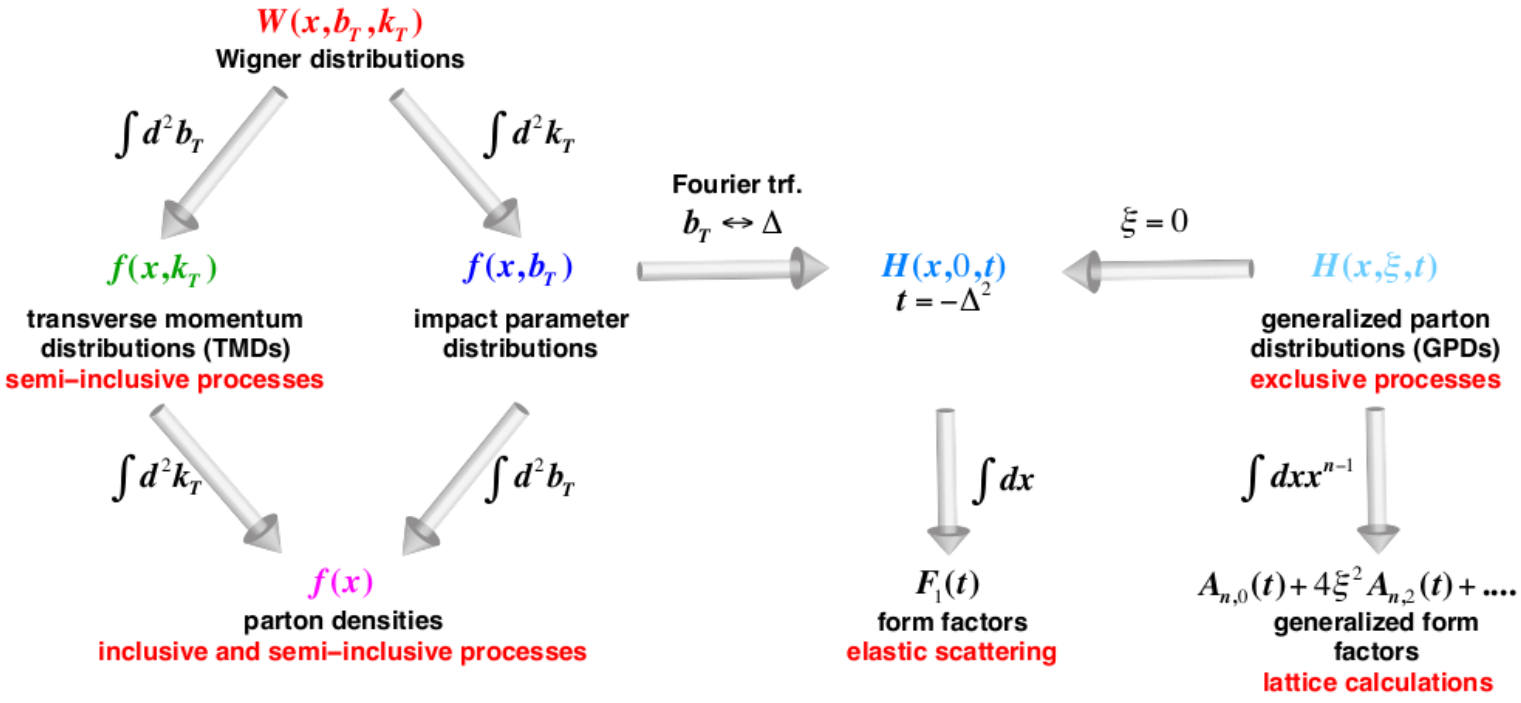
A famous proverb in English language: "One Picture Worth Ten Thousand Words" which is labeled a Chinese proverb.



- Depict the kaleidoscopic multi-dimensional landscape of the internal structure of hadrons including nucleons and nuclei.

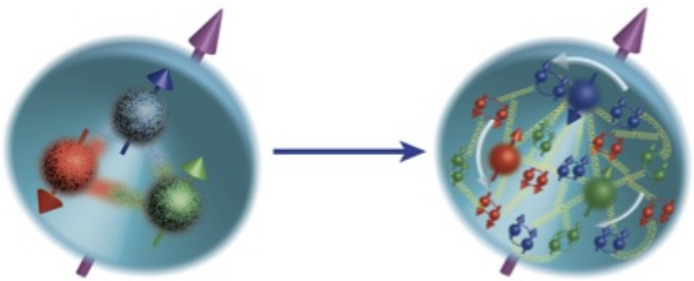
3D Tomography of Proton

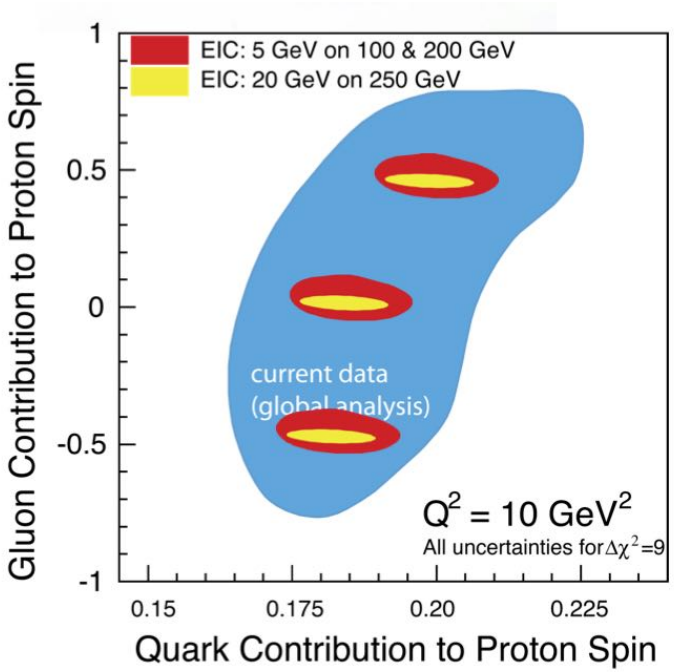
Wigner distributions [Belitsky, Ji, Yuan, 2004] ingeniously encode all quantum information of how partons are distributed inside hadrons.



[Quasi PDFs, Y. Zhao, Y.Z. Liu and X. Gao]: PDFs and Mass.

Understanding Nucleon Spin





Jaffe-Manohar decomposition

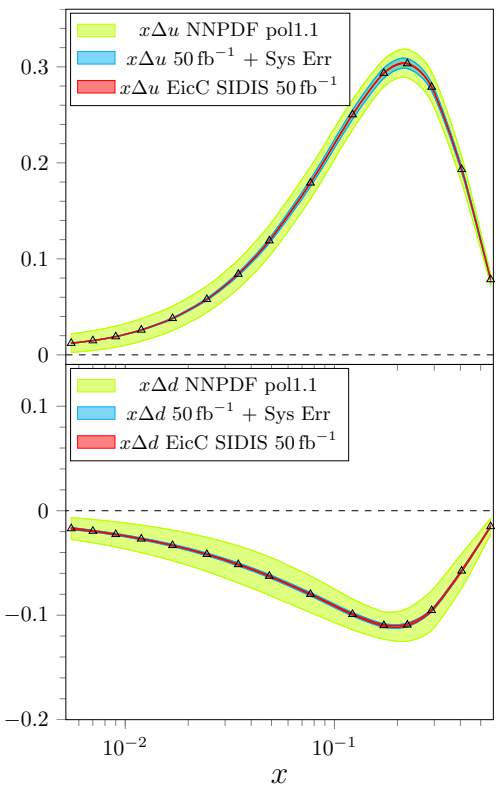
$$\frac{1}{2} = \underbrace{\frac{1}{2}\Delta\Sigma + L_q}_{\text{Quark}} + \underbrace{\Delta G + L_g}_{\text{Gluon}}$$

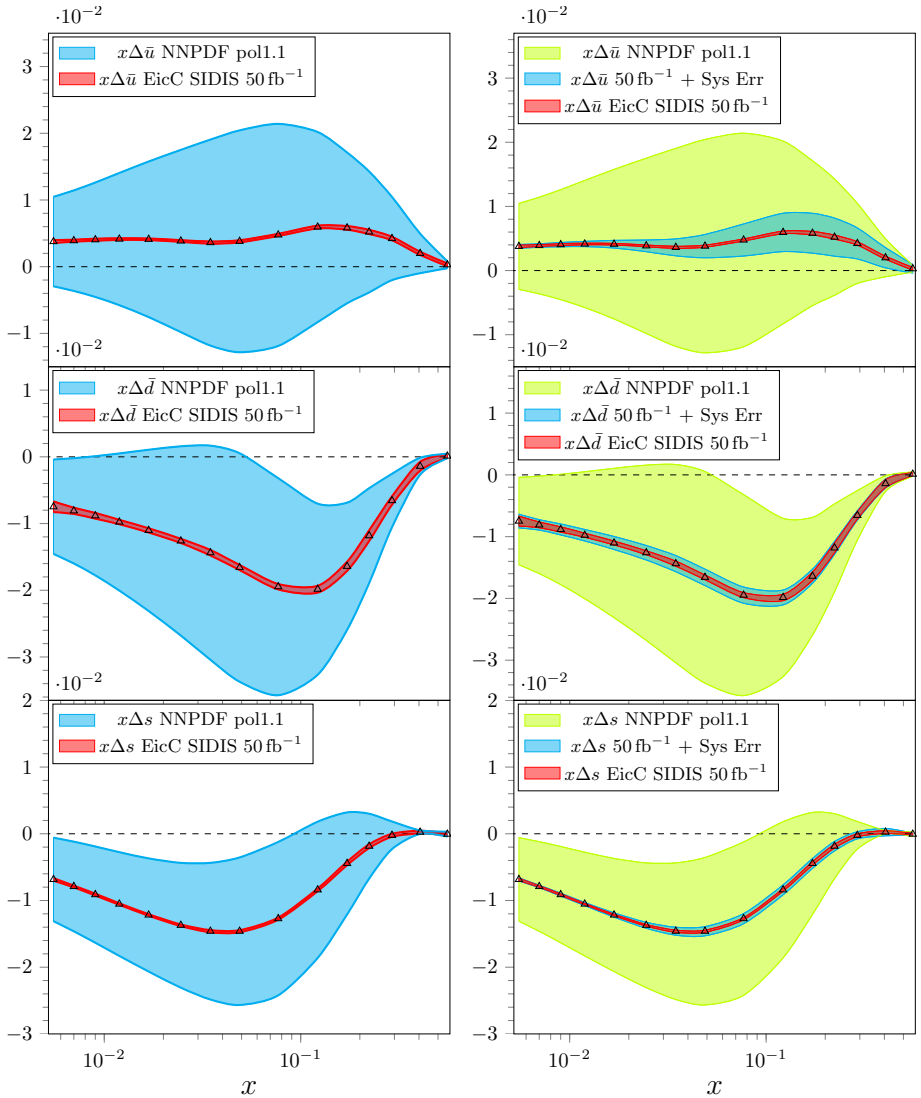
- Quark spin $\Delta\Sigma$ is only 30% of proton spin.
- The rest of the proton spin must come from the gluon spin ΔG, quark and gluon OAM $L_{q,g}$.
- Orbital motions of quark and gluon are essential.
- [χQCD]: Gluon $\Delta G \simeq 0.25$
- Complementarity between EIC and lattice.

Spin flavor Structure at EicC

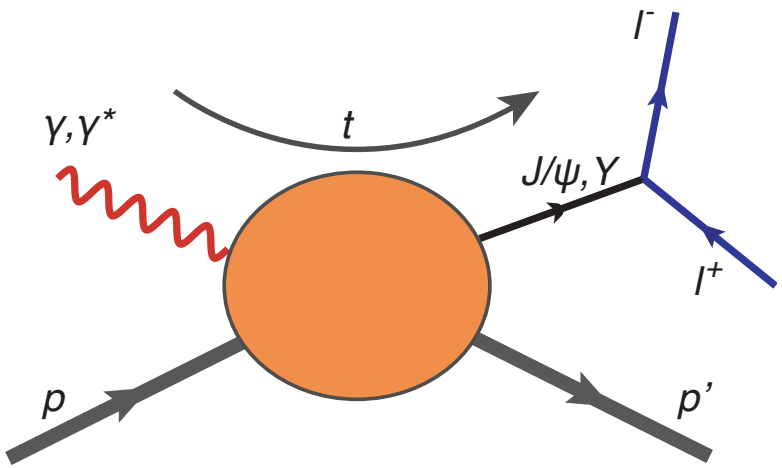
LO analysis of EicC data

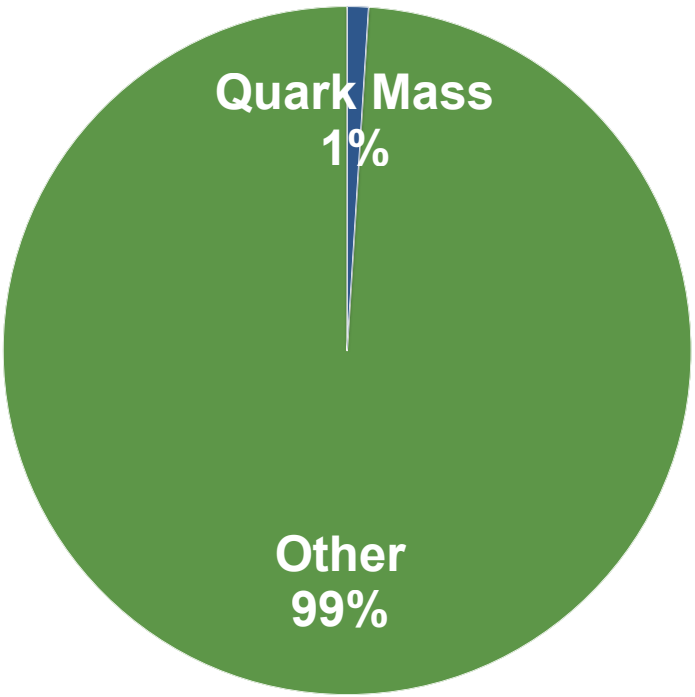
- $\pi^{\pm}$ and $K^{\pm}$ mesons
- ep: 3.5 GeV $\times$ 20 GeV
- $e\mathrm{He}^3$: 3.5 GeV $\times$ 40/3 GeV
- Luminosity ep 50 fb^{-1}





Understanding Proton Mass





Mass decomposition

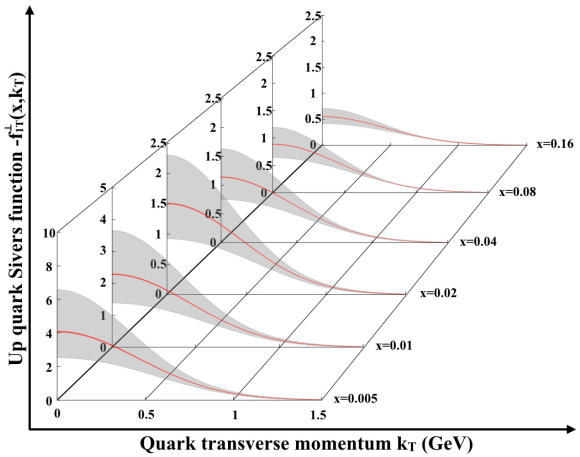
$$M = \underbrace{M_q + M_m}_{\text{Quark}} + \underbrace{M_g + M_a}_{\text{Gluon}}$$

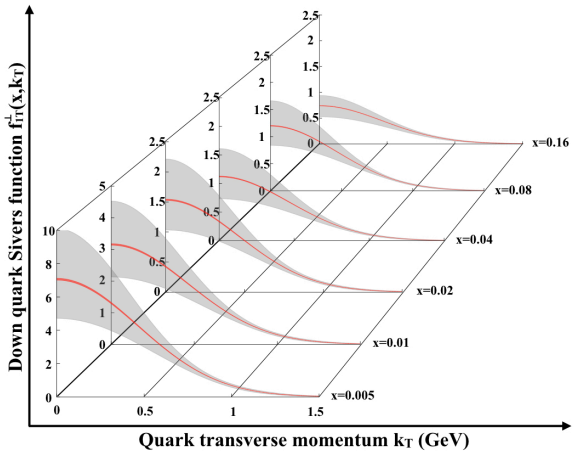
- [Somov, Joosten, Hatta, Yang]
- Complementarity between EIC and lattice. Matching?
- Interesting connection to pentaquark physics.
- Challenges in QCD.
- Pion and Kaon structure functions. [Roberts]

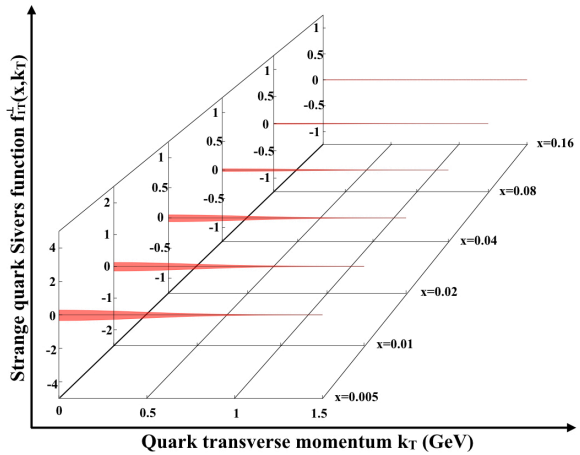
3D Distributions in Momentum Space

Access to quark Sivers function, especially the strange quark Sivers.

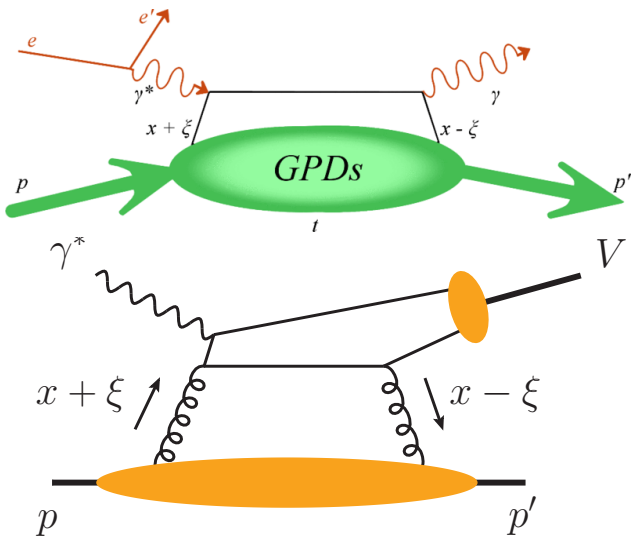
Nucleon Polarization	Quark Polarization: Un-Polarized (U)	Quark Polarization: Longitudinally Polarized (L)	Quark Polarization: Transversely Polarized (T)
U	f_1 =		$h_1^\perp$ = — Boer-Mulders
L		g_{1L} = — Helicity	$h_{1L}^\perp$ = —
T	$f_{1T}^\perp$ = — Sivers	$g_{1T}^\perp$ = —	h_1 = — Transversity $h_{1T}^\perp$ = —







3D Imaging: GPD from DVCS and DVMP

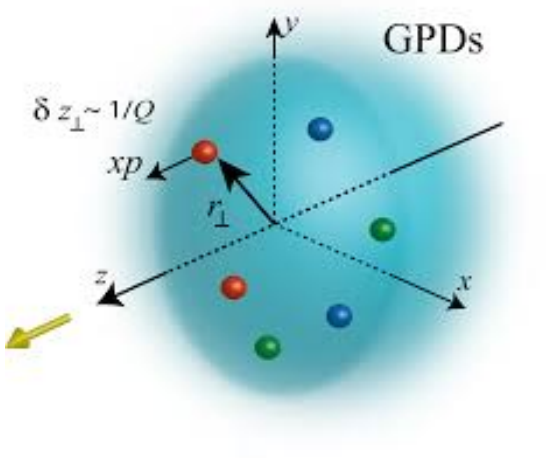


Ji Sum Rule:

$$\frac{1}{2} = J_q + J_g$$

$$J_q = \frac{1}{2}\Delta\Sigma + L_q = \frac{1}{2}\int dx x \left(H_q + E_q\right) ,$$

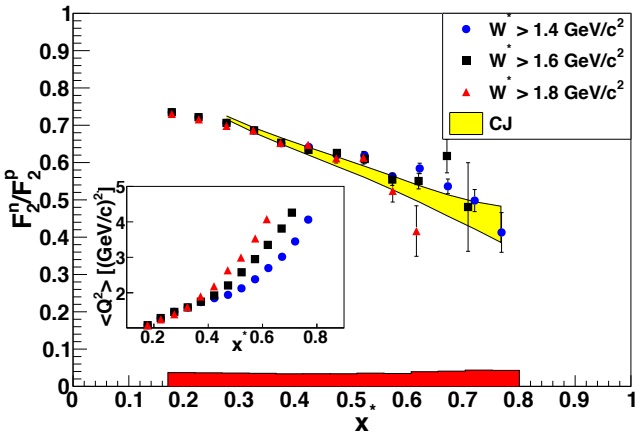
$$J_g = \frac{1}{4}\int dx \left(H_g + E_g\right) .$$



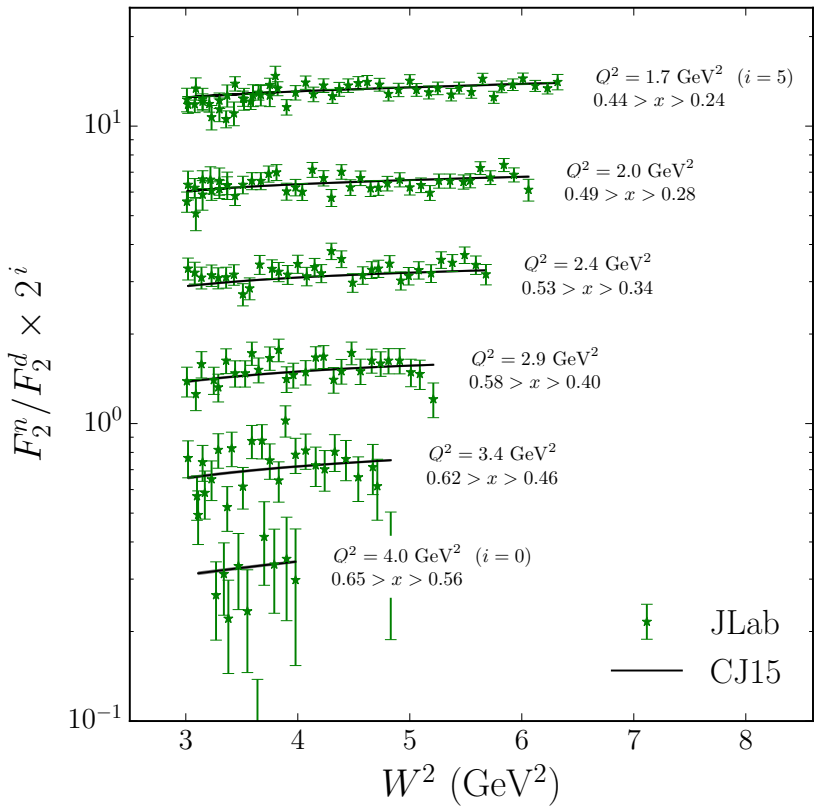
- Allows us to access to spacial distributions (which are related to GPDs via FT) of (valence and sea) quarks in the nucleon.
- Obtain the information about the quark orbital motions L_q indirectly.
- Flavor separation and sea quark GPD in DVMP.

Neutron and Deuteron structure functions

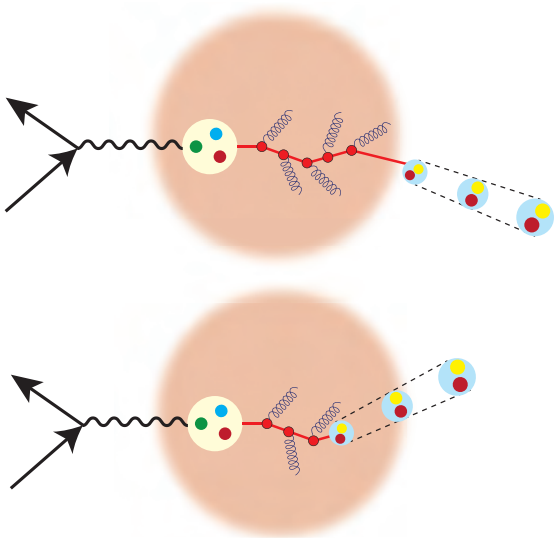
DIS on deuteron [JLab BONus exp, Phys. Rev. C 89 , 045206 (2014).]

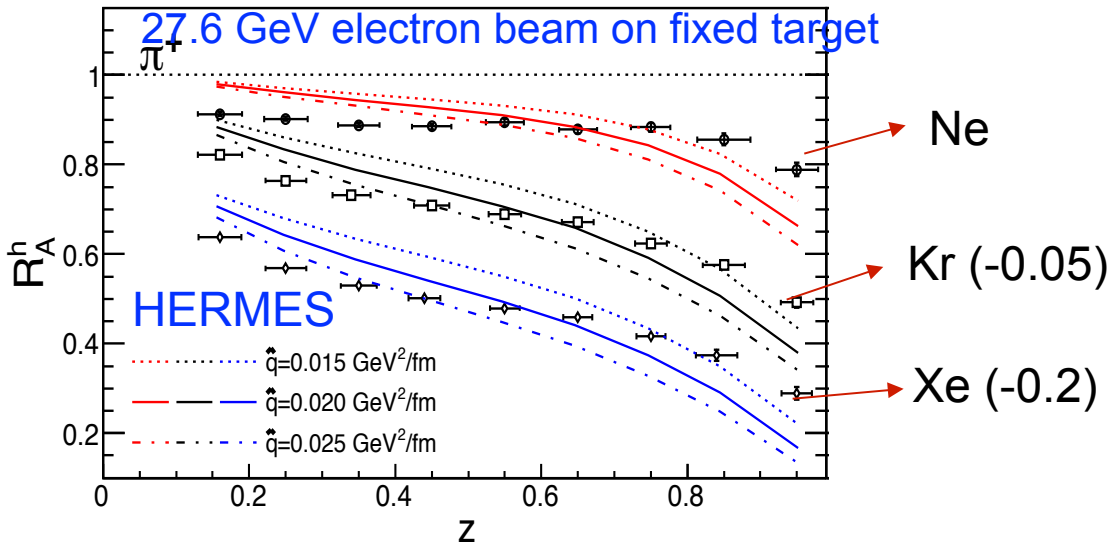


- No free neutron target.
- Use d and ^3He
- d/u ratio at large x provides insights into the structure of nucleons. [Accardi *et al*, 1602.03154]



Quark-gluons in cold nuclear medium





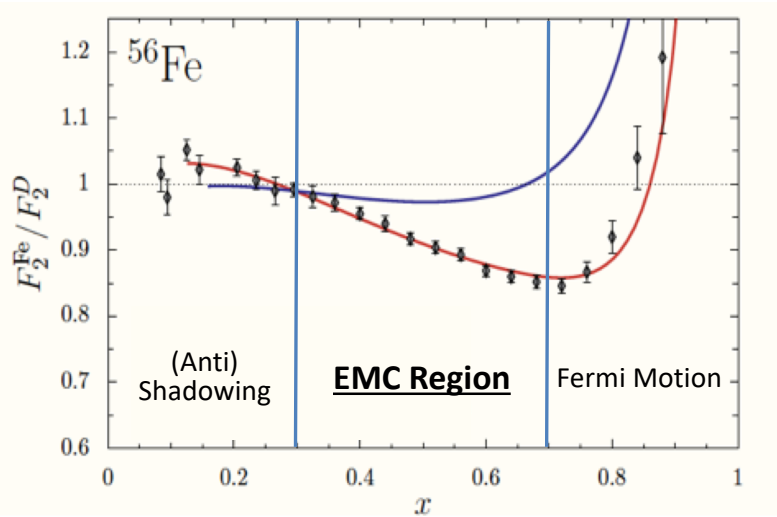
- The BDMPS formalism: the transport coefficient of cold nuclear matter $\hat{q} \sim 0.02\text{GeV}^2/\text{fm}$

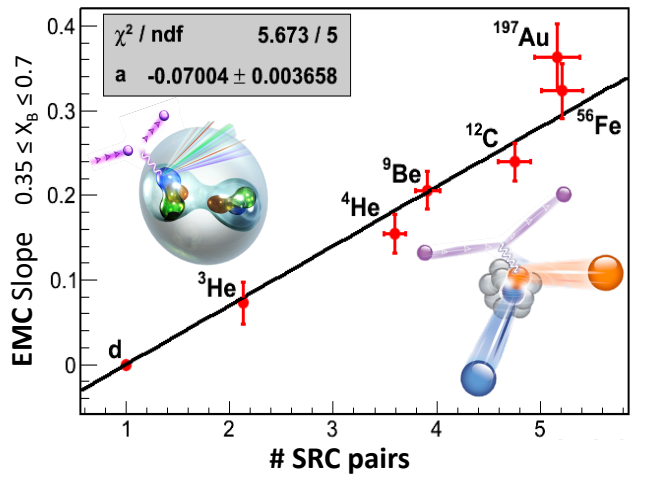
$$-\Delta E \sim 2\text{GeV}\left(\frac{L^2}{10\text{fm}}\right)^2$$

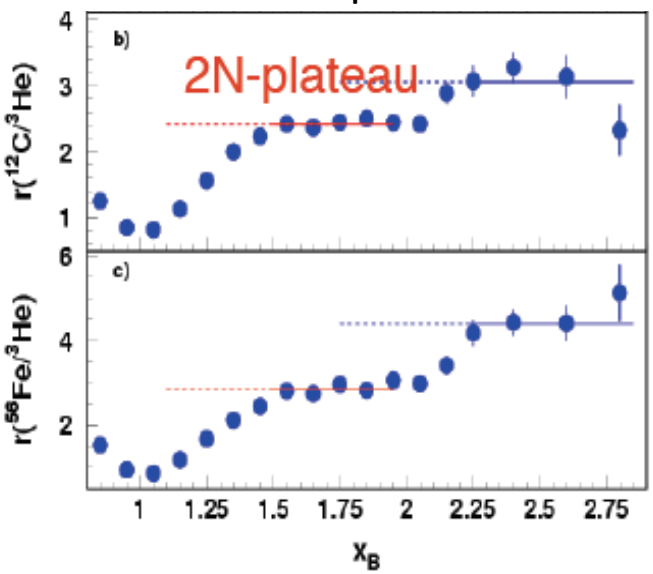
- Use heavy nuclei as femtometer detectors to study nuclear medium.
- Energy loss of light meson and heavy meson in SIDIS.
- Use different hadron to do flavor separation.

The EMC effect and short range correlations

DIS on nuclear tagets [EMC, 1983.] [CLAS, PRL, 96 (2006) 082501]



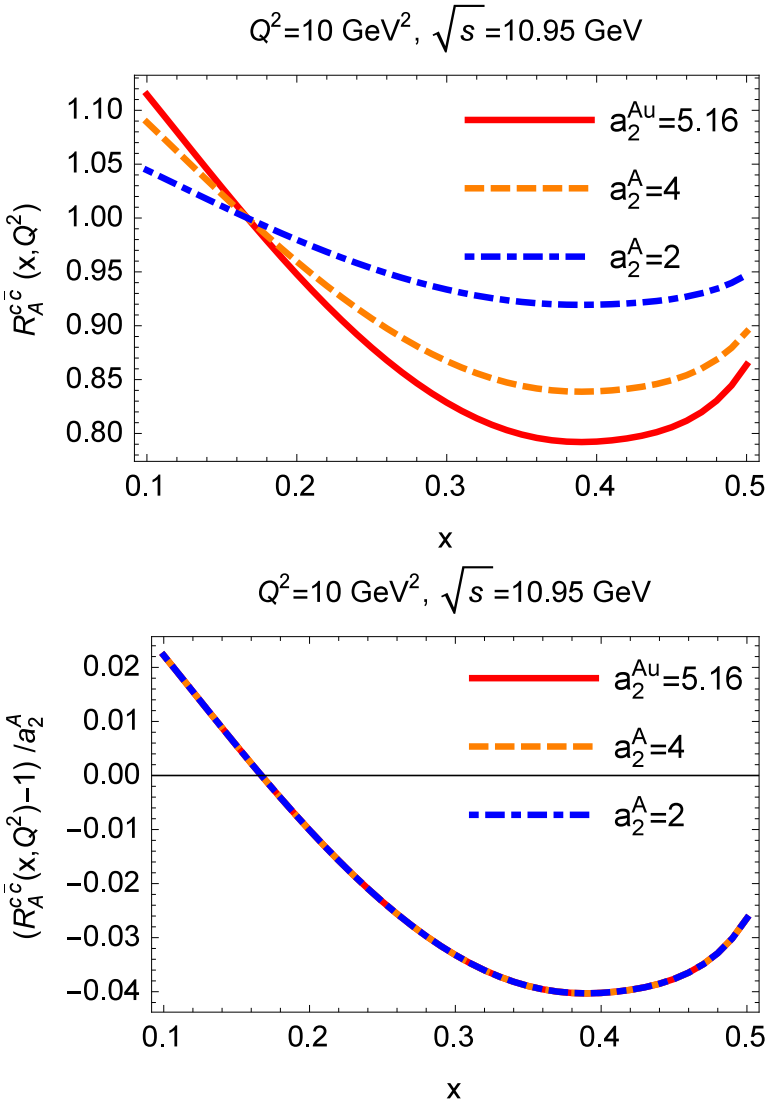




- EMC suggests: quarks move slower in nuclei.
- One of the possible explanations is SRC: pairs of nucleons with overlapping wavefunctions, with higher relative momentum and lower center of mass momentum than two unpaired nucleons.
- $x_B \equiv \frac{Q^2}{2m_N\nu}$ can be larger than 1 in eA collisions.

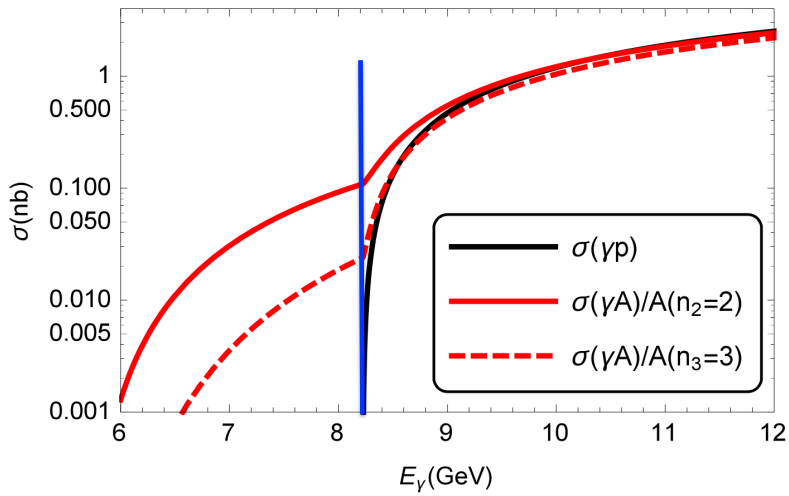
The EMC effect and short range correlations

[Xu, Yuan]: $F_2^{C\bar{C}}$ and sub-threshold J/Ψ productions to probe SRC.



$$g_A(x,Q^2) = Ag_p(x,Q^2) + 2n_{src}^A \delta\tilde{g}(x,Q^2)$$

$$a_2^A = (n_{src}^A/A)/(n_{src}^d/2)$$



- EMC effect for different nuclei seems to be described by the universal SRC pairs.